SECTION 5.0 CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Several conclusions were derived from this research project:

1. The cross-hole sonic logging method, despite certain limitations is; (a) a valid and conclusive technique in assessing the integrity of deep concrete foundations; (b) is flexible and economical for use in deep shafts; (c) is accurate and repeatable but highly sensitive to measurement errors; for example, relatively minor deviations of a tube can introduce significant deviation in the *"first arrival time"* picks that are related to the dynamic property of the medium as "apparent" velocity; (d) capable of locating structural defects and detecting velocity variations within a medium; and, (e) a two-dimensional method, which makes it difficult to interpret the results in terms of size and geometry of defects or lateral (in vertical cross-section perspective) variations in velocity distribution.
2. Accurate interpretation of CSL results is an important issue in evaluating the integrity of deep foundations. Tomography is a method that may overcome the limitations in CSL concerning the interpretation of results. Three-dimensional color-coded tomographic imaging adds an advantage to the CSL system output by allowing imaging of, the location, size, and geometry of a defect with high accuracy.
3. Tomography software separates and presents certain specific velocities representing various questionable zones of defect geometry with high resolution.
4. An important advantage of tomography is the capability to provide a visual image of lateral variations in velocity within a structure. The process is capable of determining inter-tube velocity variations of 5%, or better.
5. Laboratory measurements of the Ultrasonic Pulse Velocity (UPV) on samples of the same concrete mixture used in the tested foundation are effective to determine the velocity datum for accurately rating defects based on field velocity reductions.
6. UPV results can be used as the maximum velocity on the velocity scale (representing "good" concrete) for plotting tomographic imaging. Any zones with "degraded velocity" from the determined UPV value are considered either "*questionable*" *or* "*failed*".

7. Zero probe-offset data produce the highest range of velocities because of the smaller path length during the CSL data collection. Best aperture and therefore highest image resolution converges when combining rays from several offsets. For tomography, CSL data collection with offsets is more effective for accurately imaging concrete structures.
8. Tomography research on the Piney Creek Replacement Project has shown no-analogy between the CSL test results, tomographic interpretation, and coring results. For this case study, CSL data collection was performed four different times on the same shaft (initial test, test with the offsets, retest after 16 days of curing, and retest after pressure grouting). Every time, the CSL data has detected the defect on the same horizon but with some improvement followed by the pile repair procedure. Based on the coring results, the defect within the shaft better corresponded with 30% decrease in velocity than 20% decrease.

RECOMMENDATIONS

The project specifications should be modified to include the following:

- Three-dimensional tomographic images of the drilled shaft as a standard presentation to replace the current full waveform or XY plots of the CSL results.
- A document should be prepared and attached with the specifications that summarize CSL tomogram interpretation.
- UPV tests on concrete samples should be requested to be performed in conjunction with the concrete strength tests. Concrete samples should be of the same mix as that used for constructing the tested foundation.
- A customizes tomographic imaging software specifically for use with CSL should be developed.
- CSL systems with a single transmitter and multiple receivers should be used for collecting multiple offset data rapidly.
- The CSL tests should be conducted by FHWA or Department of transportation specialized teams and not by the contractor.

Currently 3-D tomographic imaging software can be purchased from companies such as GeoTomo, Texas, and Hampson-Russell software Services Ltd, Canada. Other engineering and environmental consulting companies provide services to the CSL users. For example NSA engineering, Inc., has an on line service where a program called CSLTOMO3D may be accessed remotely through the internet network connection for data processing and output. Several other CSL service companies also have the capability to perform 2-D tomographic imaging. ***The Government does not endorse any one CSL company, system, or tomographic imaging method.***